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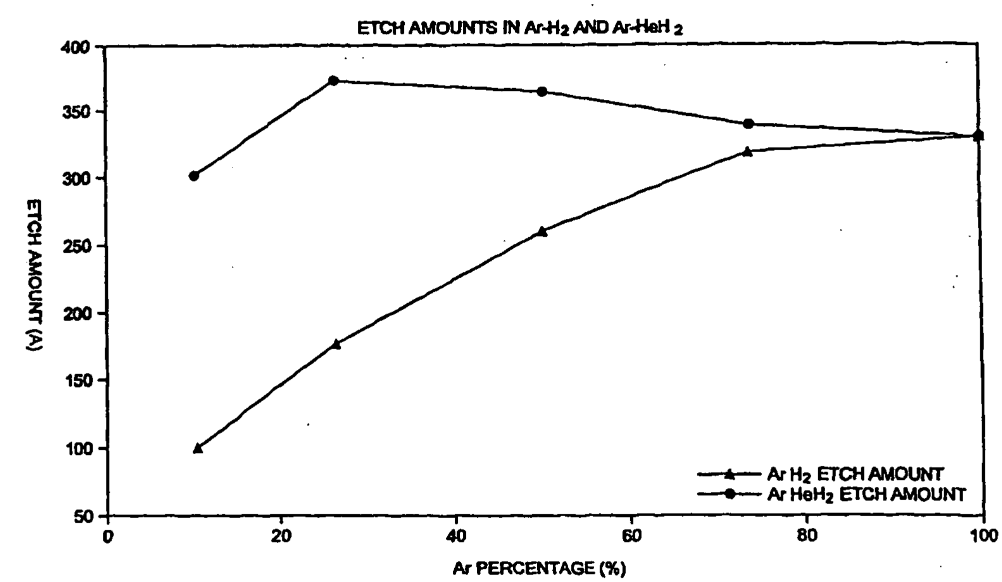
(54) Title: PLASMA PRECLEAN WITH ARGON, HELIUM, AND HYDROGEN GASES



(57) Abstract

The present invention provides a method and apparatus for precleaning a patterned substrate with a plasma comprising a mixture of argon, helium, and hydrogen. Addition of helium to the gas mixture of argon and hydrogen surprisingly increases the etch rate in comparison to argon/hydrogen mixtures. Etch rates are improved for argon concentrations below about 75 % by volume. RF power is capacitively and inductively coupled to the plasma to enhance control of the etch properties. Argon, helium, and hydrogen can be provided as separate gases or as mixtures.

PLASMA PRECLEAN WITH ARGON, HELIUM, AND HYDROGEN GASES

Field of the Invention

The present invention relates to an apparatus and method for forming integrated plug and wire interconnects on a substrate having submicron features. More particularly, the present invention relates to a sequence for forming metal interconnects wherein a patterned dielectric layer is exposed to a plasma containing an inert gas and a reactive gas.

Background of the Invention

Sub-half micron multilevel metallization is one of the key technologies for the next generation of very large scale integration ("VLSI"). The multilevel interconnects that lie at the heart of this technology require planarization of high aspect ratio features such as plugs and other interconnects. Reliable formation of these interconnects is very important to the success of VLSI and to the continued effort to increase circuit density and quality on individual substrates and die.

Conventional chemical vapor deposition (CVD) and physical vapor deposition (PVD) techniques are used to deposit electrically conductive material into the contact holes, vias, trenches, or other patterns formed on the substrate. One problem with conventional processes arises because the contact holes or other patterns often comprise high aspect ratios, i.e., the ratio of the height of the holes to their width or diameter is greater than 1. The aspect ratio of the holes increases as advances in technology yield more closely spaced features.

The presence of native oxides and other contaminants within a small feature typically results in voids by promoting uneven distribution of the depositing metal. The native oxide typically forms as a result of exposing the exposed film layer/substrate to oxygen. Oxygen exposure occurs when moving substrates between processing chambers at atmospheric conditions, or when the small amount of oxygen remaining in a vacuum chamber contacts the wafer/film layer, or when a layer is contaminated by etching. Other contaminants within the features can be sputtered material from an oxide over-etch, residual photoresist from a stripping process, leftover hydrocarbon or fluorinated hydrocarbon polymers from a previous oxide etch step, or redeposited material from a preclean sputter etch process. The native oxide and other contaminants create regions on the substrate which interfere with film formation, by creating regions where film growth is stunted. Regions of increased growth merge and seal the small features before regions of

Precleaning is preferably conducted with a mixture of an inert gas, typically argon, and a reactive gas, typically hydrogen. Mixtures of argon and hydrogen remove both reactive and non-reactive contaminants and can be used to modify the shape of contact holes, vias, trenches and other patterns to improve subsequent metal deposition processes. Increasing the argon content in the preclean mixture provides a corresponding increase in the etch rate of the preclean process and a corresponding decrease in the etch uniformity of the preclean process. Hydrogen must be included in the mixture to effectively remove reactive compounds or contaminants such as copper oxides and hydrocarbons. Precleaning patterned substrates with a mixture of argon and any amount of hydrogen provides a lower etch rate and an increased etch non-uniformity than precleaning with argon.

A preclean process having both high concentrations of reactive gases and improved etch rates would substantially promote removal of contaminants by addition of the reactive gases.

Summary of the Invention

The present invention provides a method and apparatus for precleaning a patterned dielectric layer to remove native oxides and polymers of hydrocarbons and fluorinated hydrocarbons from small feature sizes (such as quarter micron widths and smaller) and which may have high aspect ratios. Generally, the present invention provides a method and apparatus for providing a plasma comprising a mixture of argon, helium, and hydrogen to preclean a patterned substrate. Addition of helium to the gas mixture of argon and hydrogen surprisingly increases the etch rate in comparison to argon/hydrogen mixtures. Etch rates are improved for argon concentrations below about 75% by volume. The etch rate actually increases as the argon volume % drops from about 75% to about 25%, and then the etch rate declines as the argon volume % is further reduced.

Control of the etch rate is provided by controlling the mixture of argon, helium, and hydrogen, and by controlling the chamber pressure. Furthermore, RF power is capacitively and inductively coupled to the plasma to enhance control of the etch properties. Argon, helium, and hydrogen can be provided as separate gases or as mixtures, however, mixing of helium with 5% by volume of hydrogen is preferred for safety and etch performance.

Al, Cu, or TiN sublayers. The feature exposes the sublayer so that the feature can be filled with a conductive or semi-conductive material which connects the sublayer and a subsequent metal interconnect layer to be deposited on the dielectric layer. Etching of the features in the dielectric typically leaves contaminants which should be removed to improve filling of the features and ultimately improve the integrity and reliability of the devices formed.

After etching of the dielectric layer, the features can have damaged silicon or metal residues within the features from over-etching of the dielectric layer. The features can also contain residual photoresist on the feature surfaces from the photoresist stripping and/or ashing process or residual hydrocarbon or fluorinated hydrocarbon polymers from the dielectric etch step. The features may also contain redeposited material on the feature surfaces following a sputter etch preclean process. These contaminants can migrate into the dielectric layer or can interfere with the selectivity of metallization by promoting uneven distribution of the depositing metal. The presence of the contaminants also can increase the resistance of the deposited metal by substantially narrowing the width of the feature, and thus creating a narrowed portion in the metal forming the via, contact line , or other conductive feature.

The submicron features that are cleaned and filled in accordance with the present invention, are formed by conventional techniques which deposit a dielectric material over a surface on a semiconductor substrate. Any dielectric material, whether presently known or yet to be discovered, may be used and is within the scope of the present invention, including low dielectric materials such as organic polymers and aerogels. The dielectric layer may comprise one or more distinct layers and may be deposited on any suitable deposition enhancing sublayer. The preferred deposition enhancing sublayers include conductive metals such as Al and Cu, and barrier surfaces such as TiN, Ta, and TaN.

Once deposited, the dielectric layer is etched by conventional techniques to form vias, contacts, trenches or other submicron features. The features will typically have a high aspect ratio with steep sidewalls. Etching of the dielectric layer may be accomplished with any dielectric etching process, including plasma etching. Specific techniques for etching silicon dioxide include such compounds as carbon tetrafluoride and silicon hexafluoride. However, patterning may be accomplished on any layer using any method known in the art.

of gas injection holes. The gas distribution system 119 supplies Ar, He, and H_2 gases which are typically metered by mass flow controllers 136. Hydrogen may also be supplied as a mixture with helium having about 5% hydrogen by volume for safe delivery of the hydrogen. However, a separate hydrogen line is still provided to attain hydrogen concentrations greater than 5% by volume. A pedestal 122, which is arranged to hold a wafer (not shown), has a quartz body 121 surrounding the sides and bottom of a conductive portion 120. An insulating layer 129 may be placed between the conductive portion 120 of the pedestal 122 and the wafer.

RF power from an RF source 134 is applied capacitively to the conductive portion 120 of the pedestal 122. A RF match box 135 adjusts the chamber impedance to optimize power transfer between the power source 134 and the pedestal 122. Typical RF frequencies are from about 2 MHz to about 60 MHz at power levels from about 10W to about 500W.

Additional power is inductively supplied to the plasma by energizing coils 125 wound exterior to the quartz dome 117 and supported by the cover 127. An alternating axial electromagnetic field is produced in the chamber 111 interior to the winding of the coils 125. Generally, an RF frequency between 200 KHz and 16 MHz is employed. A 2 MHz frequency is common. An RF source 132 operating at this frequency is coupled to the coil 125 by matching network 133.

The flow of argon preferably ranges from about 5 to about 50 sccm, and the flow of helium/hydrogen preferably ranges from about 0 sccm to about 2000 sccm for 200 mm substrates. Chamber pressures are between about 1 mTorr and about 200 mTorr. The plasma treatment effectively cleans, treat, and/or modifies the patterned surface in 10 to 150 seconds. After precleaning, a CVD or PVD metal layer is deposited on an optional liner or nucleation layer.

Examples

The precleaning steps of the present invention have been combined in the preclean chamber shown in Figure 3 to successfully clean features etched in a dielectric layer having a copper or silicon sublayers prior to filling of the features with Cu, Al, or W plugs. The chamber was stabilized for 5 seconds at a pressure of 5-20 mTorr with a mixture of H_2, He, and Ar. The features were then cleaned for 60 seconds by applying from 300W to 450W of 2 MHz RF power to the coil and 10W to 300W of 13.56 MHz RF power to the pedestal.

What is claimed is:

1. A method for processing a substrate, comprising exposing a patterned substrate surface to a plasma comprising argon, helium and hydrogen in a processing chamber.

2. The method of claim 1, wherein the plasma comprises less than about 75% by volume of argon.

3. The method of claim 2, wherein hydrogen is provided to the processing chamber in a mixture of about 95% helium by volume and about 5% hydrogen by volume.

4. The method of claim 1, wherein etch rate increases when helium content is increased.

5. The method of claim 1, wherein the substrate surface comprises silicon oxide or silicon nitride.

6. The method of claim 1, wherein the plasma is capacitively and inductively powered.

7. The method of claim 1, wherein the processing chamber is maintained at a pressure from about 1 mTorr to about 200 mTorr.

8. A method for processing a substrate, comprising:

(a) exposing a patterned substrate surface to a plasma comprising argon, helium and hydrogen in a reaction chamber; and

(b) increasing the helium content of the plasma to increase etching of the patterned substrate surface.

9. The method of claim 8, wherein the plasma comprises less than about 75% by volume of argon.

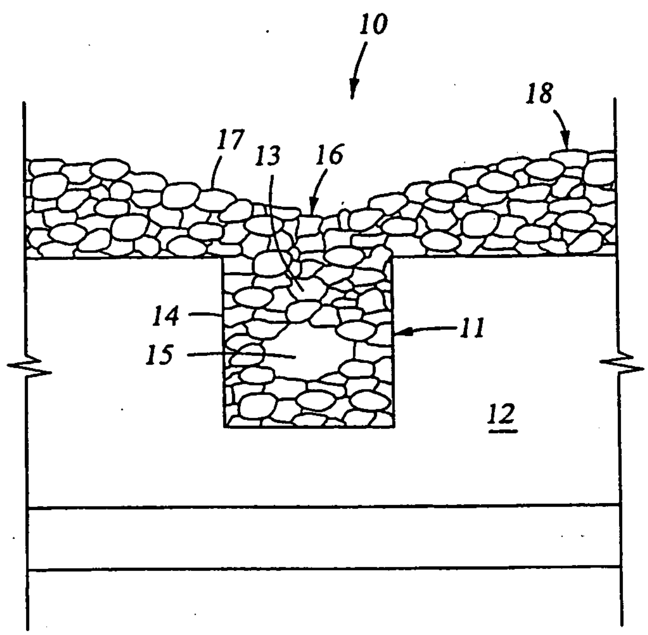


Fig. 1
(PRIOR ART)

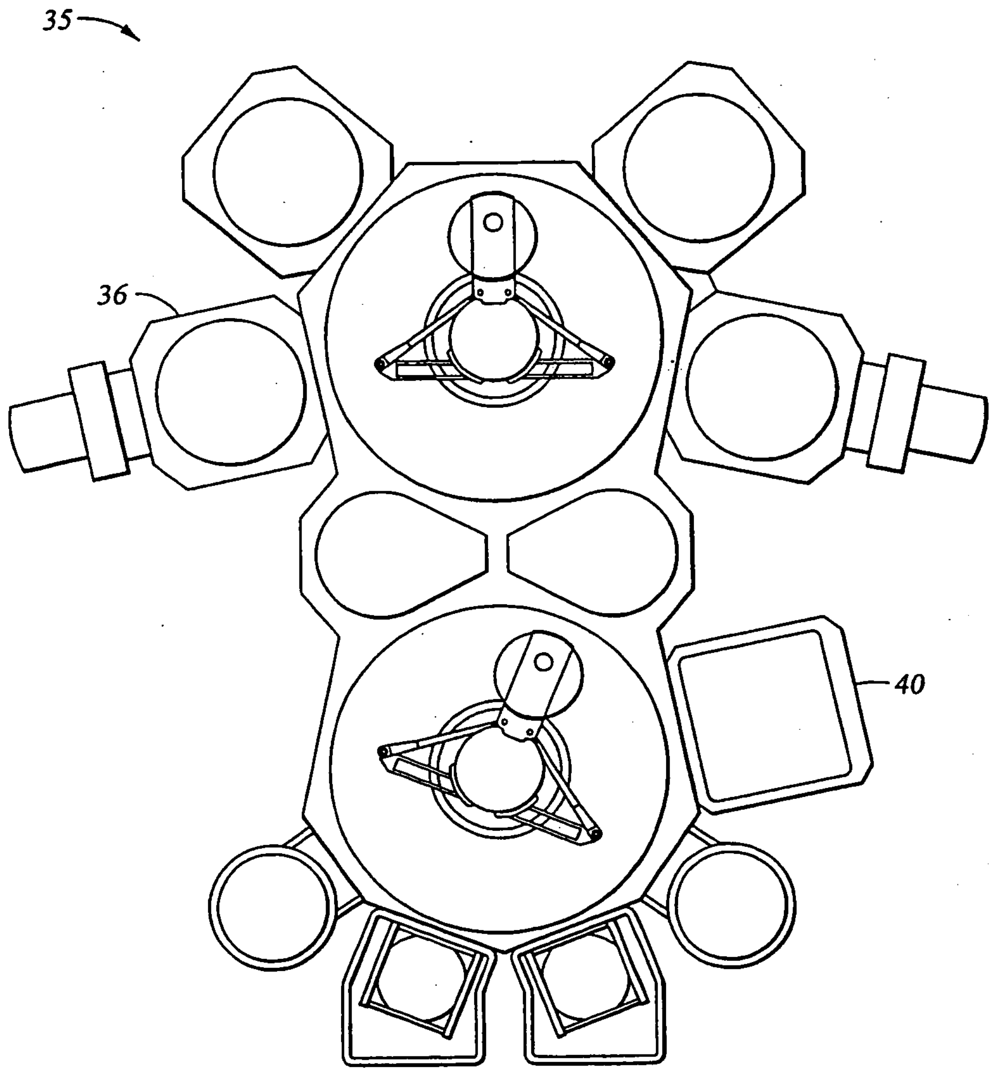


Fig. 2

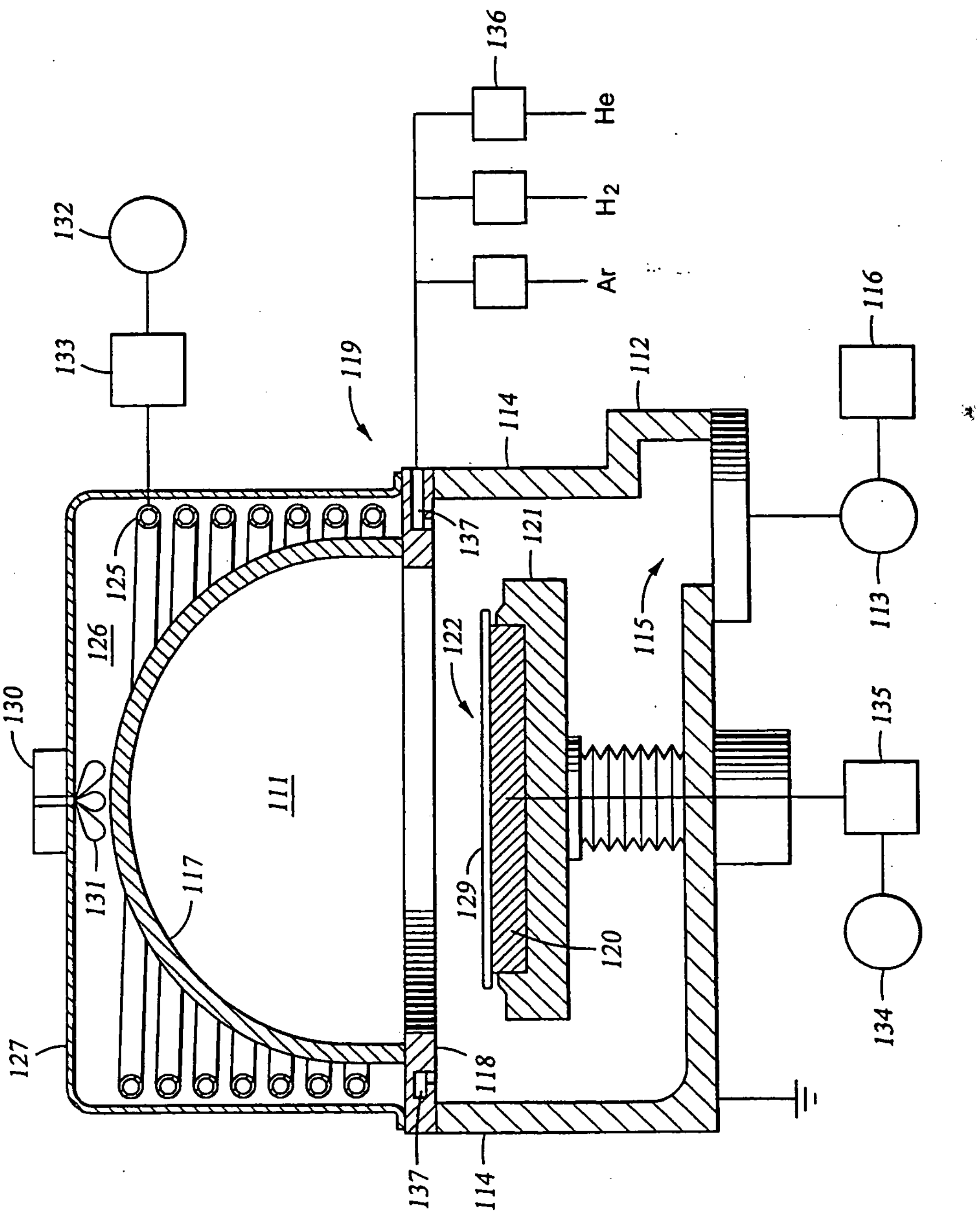

136
He
H_2
Ar
132
133
119
116
112
114
137
121
125
126
122
115
113
130
111
135
131
117
129
120
134
127
118
137
114

Fig. 3

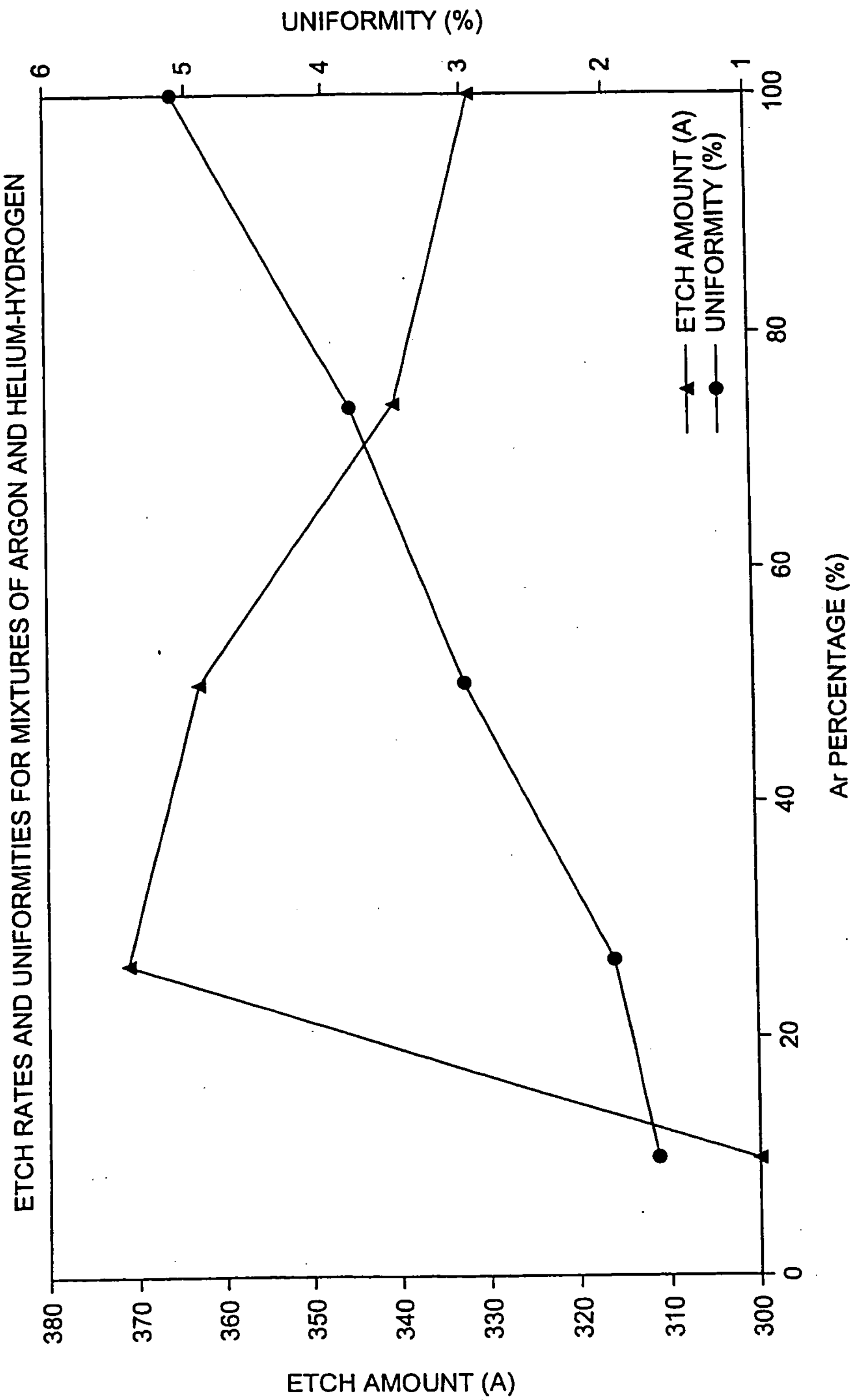

ETCH RATES AND UNIFORMITIES FOR MIXTURES OF ARGON AND HELIUM-HYDROGEN
UNIFORMITY (%)
6
5
4
3
2
1
ETCH AMOUNT (A)
UNIFORMITY (%)
380
370
360
350
340
330
320
310
300
ETCH AMOUNT (A)
0
20
40
60
80
100
Ar PERCENTAGE (%)

Fig. 4

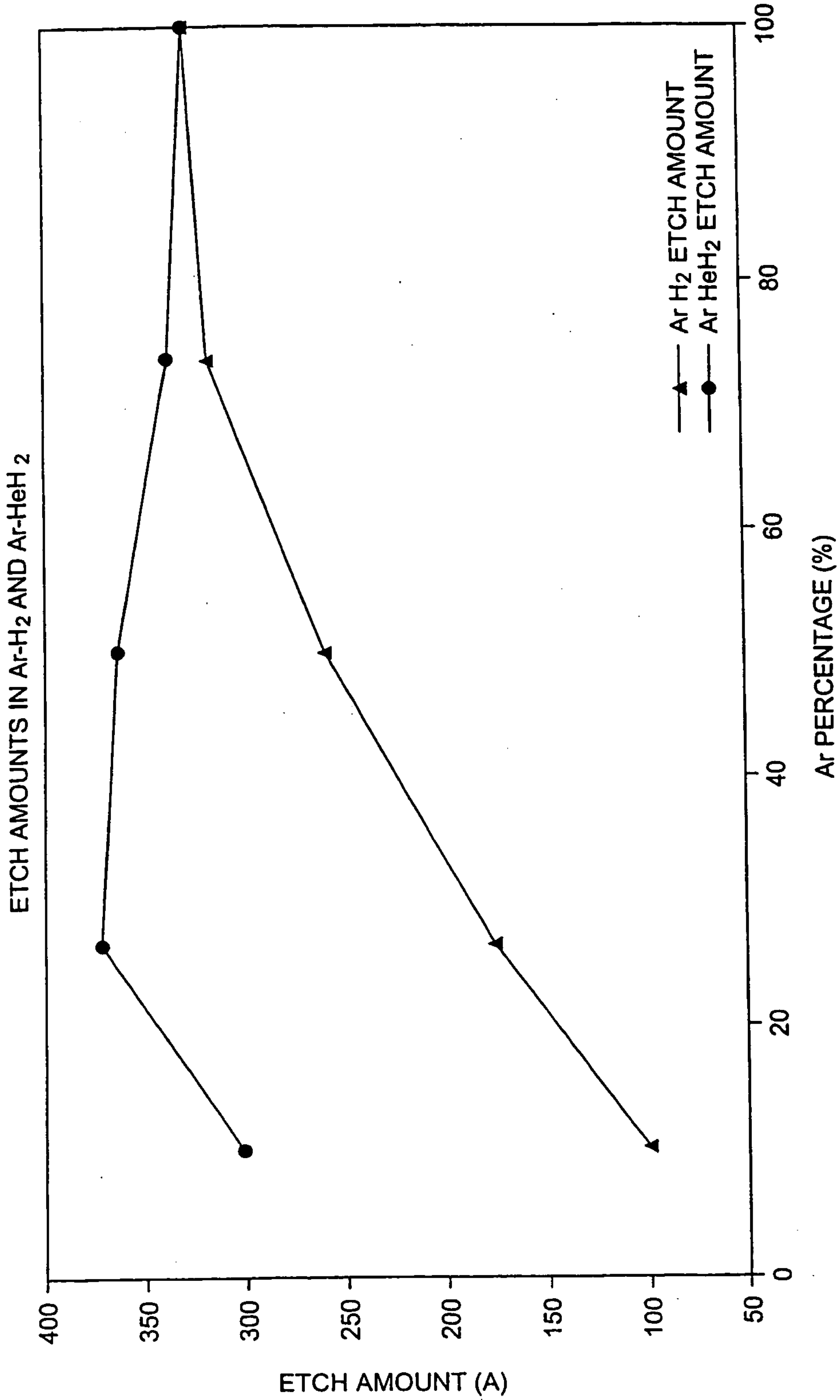

ETCH AMOUNTS IN Ar-H_2 AND Ar-HeH 2
Ar H_2 ETCH AMOUNT
Ar HeH_2 ETCH AMOUNT
ETCH AMOUNT (A)
400
350
300
250
200
150
100
50
Ar PERCENTAGE (%)
0
20
40
60
80
100

Fig. 5

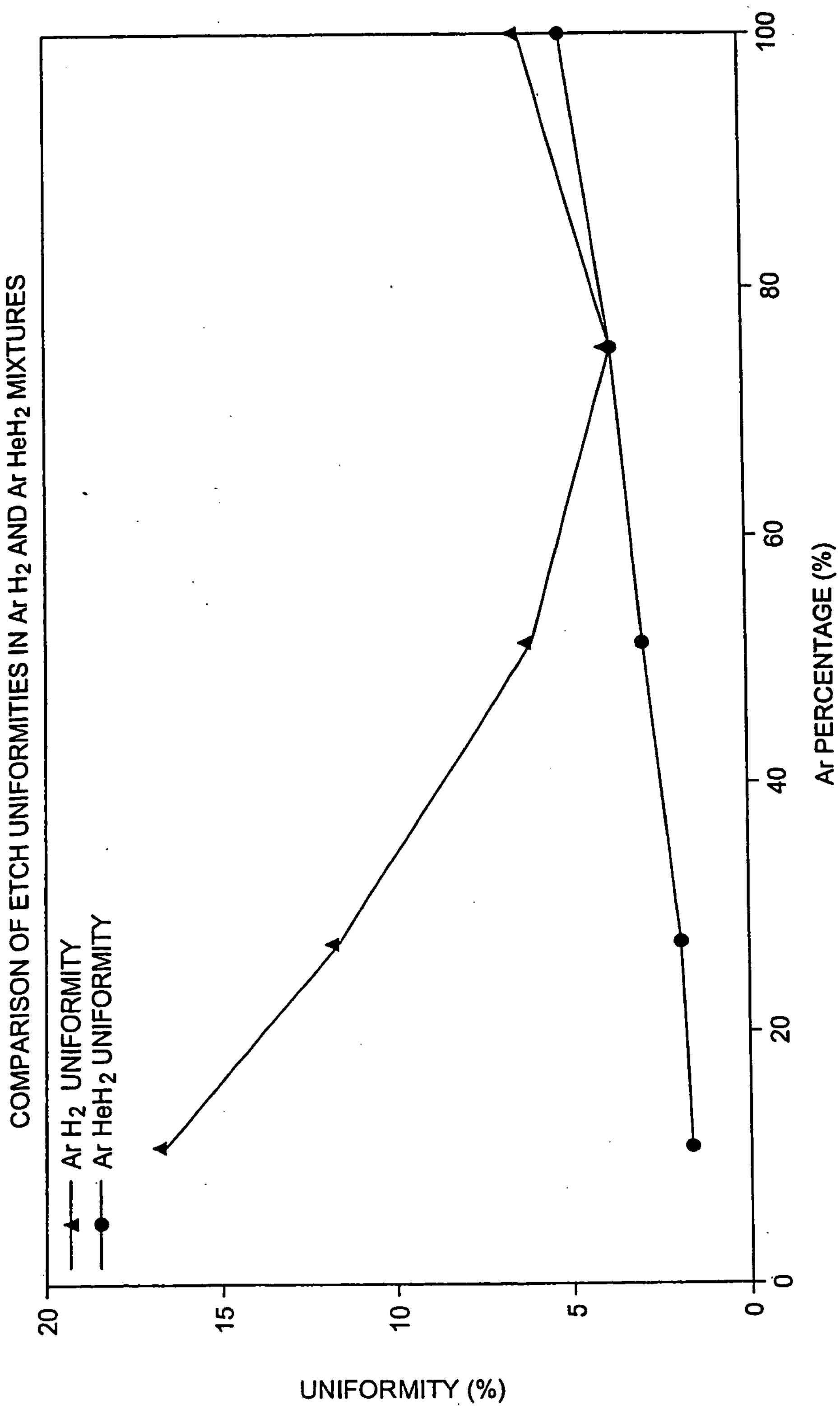

COMPARISON OF ETCH UNIFORMITIES IN Ar H2 AND Ar HeH2 MIXTURES
Ar H2 UNIFORMITY
Ar HeH2 UNIFORMITY
UNIFORMITY (%)
0
5
10
15
20
Ar PERCENTAGE (%)
0
20
40
60
80
100

Fig. 6

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/27829

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L21/311 //H01L21/768

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L C23C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	EP 0 430 303 A (APPLIED MATERIALS INC) 5 June 1991 (1991-06-05) column 2, line 35 -column 4, line 39 ---	1,5,7 6 2,6,8,9, 11-14, 16,17
X A	EP 0 849 779 A (TEXAS INSTRUMENTS INC) 24 June 1998 (1998-06-24) column 3, line 29 -column 6, line 56; figure 2 --- -/--	1,5,7 8,11,13, 14,16,17

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 March 2000	24/03/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Köpf, C

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 99/27829

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